EARTHQUAKE HAZARD IN THE MEMPHIS, TENNESSEE, AREA

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There is a difference to be marked between hazard and risk. The two are most easily distinguished by answering the question: Can the actions of people have any effect on the situation? Hazard cannot be lessened or increased but risk can. The earthquake <u>hazard</u> in Memphis, Tennessee, is an inheritance of geographic location and is due to the city's proximity to the New Madrid seismic zone; it cannot be changed by man. Earthquake <u>risk</u> is the immediate danger posed to the population and it can be substantially altered by a number of actions, most significantly, improved construction and siting of buildings. The purpose of this paper is to give a brief introduction to the seismic hazard in Memphis, Tennessee.

THE NEW MADRID SEISMIC ZONE

The New Madrid seismic zone is depicted in Figures 1 and 2. Figure 1 shows the instrumentally located epicenters for the past nine years; the main branches of the seismic zone are delineated by the concentrated pattern of epicenters within the small box of Figure 1. Figure 2 shows the relationship of the zone to Memphis and Shelby County and to the major critical facilities in the surrounding region. The generalized modified Mercalli isoseismals of Algermissen et al. (1983) are superimposed; the contours are estimated as combined effects of maximum magnitude events in the northern and southern portions of the zone. A single event would not produce these estimated intensities at all locations.

The New Madrid seismic zone is regarded by seismologists and disaster response planners as the most hazardous zone east of the Rocky Mountains (Johnston, 1982) There are three basic reasons for this estimation:

1. In the winter of 1811-1812, the zone produced three of the largest earthquakes known to have occurred in North America (M_S 8.5, 8.4, and 8.8) and hundreds of damaging aftershocks (Nuttli, 1983).

2. A major geological structure--an ancient crustal rift--has been identified through a decade of extensive research (McKeown and Pakiser, 1982). The rift underlies the shallow

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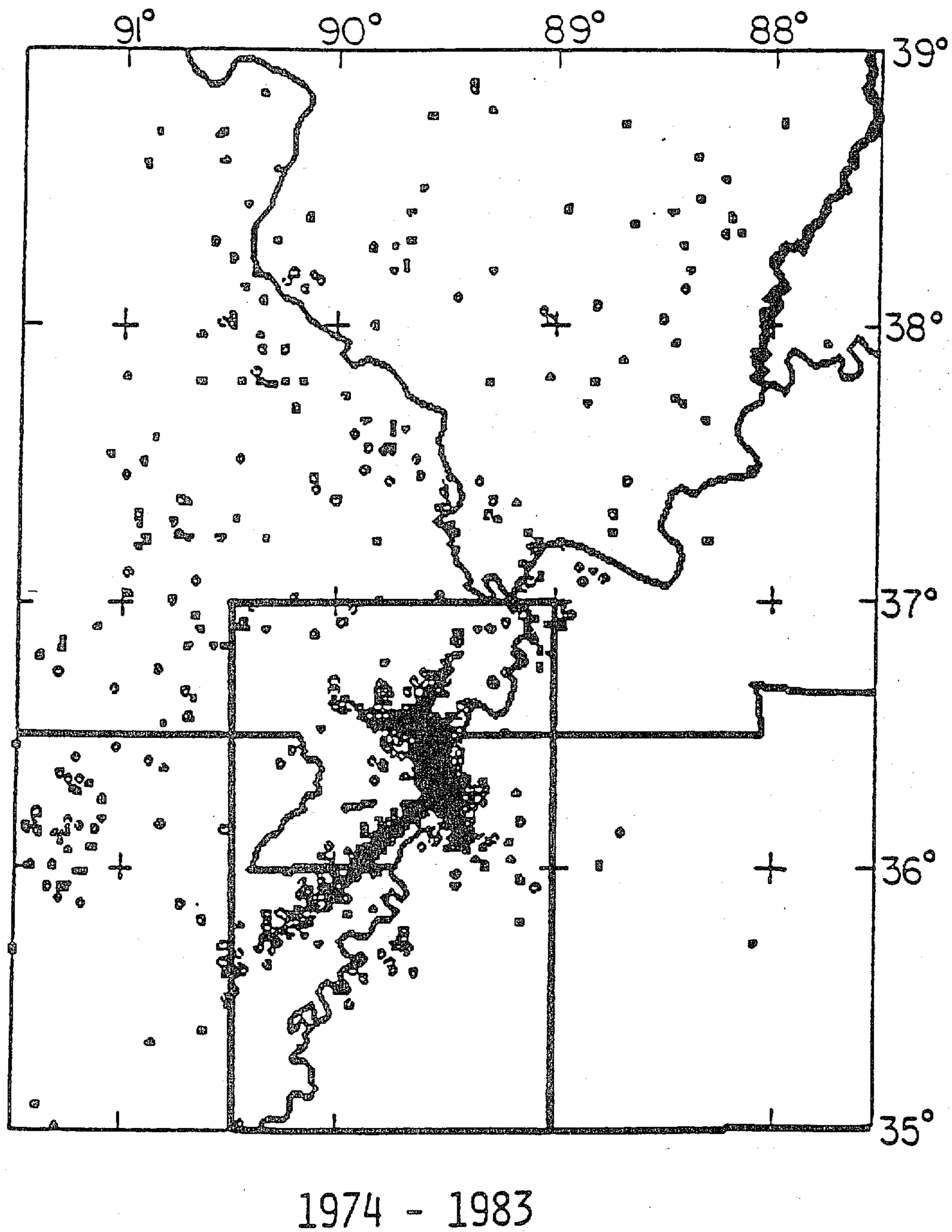

FIGURE 1 Map of the central United States with the 1974-1983 instrumental seismicity data set (Stauder and others, 1974-1983). The boundaries of the two source zones used for frequency-magnitude determination are: Large zones, 35.0 -37.0 N/89.0 -91.5 W.

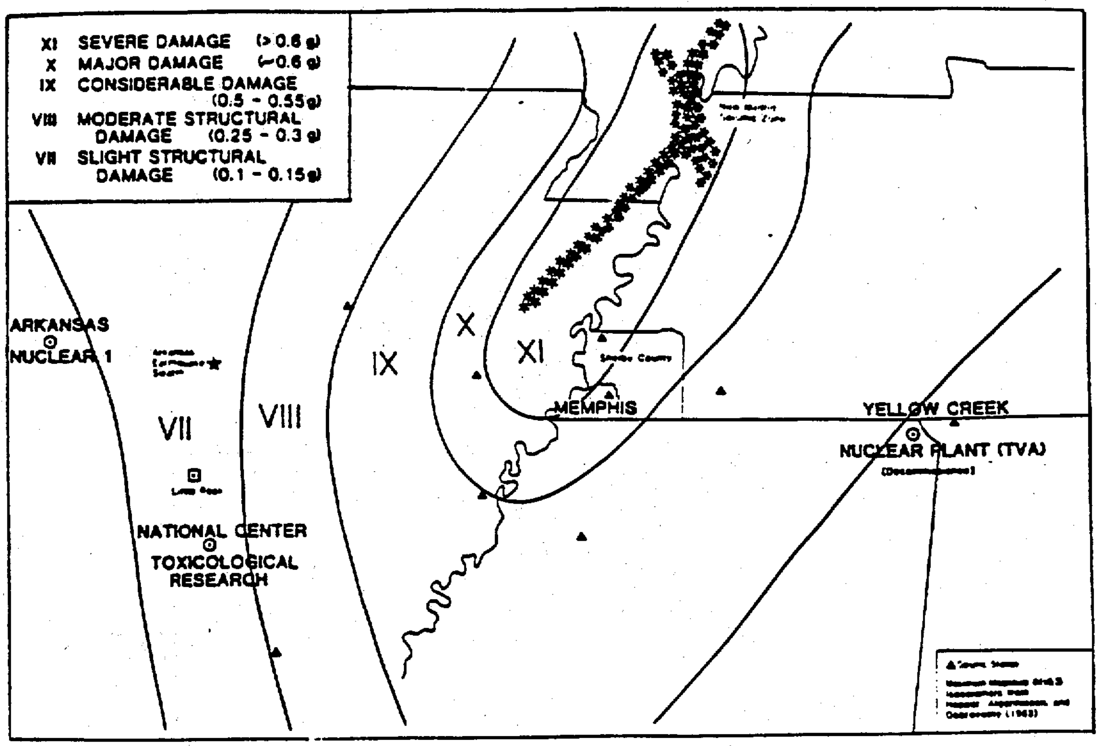

FIGURE 2 The relation of Memphis, Tennessee, and Shelby County to the New Madrid seismic zone. Also shown are major critical facilities in the region and Modified Mercalli isoseismals for a "composited" maximum magnitude New Madrid earthquake.

sediments of the Mississippi embayment and is of such character and dimension that it could generate major earthquakes.

3. The zone is still quite seismically active (Figure 1). More than 2,000 earthquakes (of which 97 percent have been too small to be felt) have been detected in the zone since 1974.

These three observations--past great earthquakes, identified geological structure, and continuing activity--constitute the reasons for the high hazard potential with which the New Madrid zone is presently regarded.

EARTHQUAKE PROBABILITY

Without a doubt, the most frequently asked and least satisfactorily answered question concerning the earthquakes of the New Madrid seismic zones is: When is the next major earthquake going to happen? Seismology cannot now (nor in the near future) answer this question in a deterministic fashion (i.e., accurately predict earthquakes), but a probabilistic assessment is possible. In a recent study, Johnston and Nava (1985) estimated the probability of occurrence of large New Madrid earthquakes for two time periods--by the end of the century and within a representative lifetime (15 and 50 years, respectively) The estimates are based on magnitude: (1) a body-wave magnitude, m_b, of 6.0 (or equivalently a surface-wave magnitude, M_s, of 6.3) which could be destructive over an area of one or more counties and (2) a body-wave magnitude of 7.0 (surface-wave magnitude of 8.3) which is considered equivalent to a repeat of one of the great New Madrid events of 1811-1812. Using these magnitude categories, the determined probabilities are as follows:

	Probability (%)	
Body Wave Magnitude	1985 to 2000	1985 to 2035
m_b 6.0 (M_s 6.3)	40-63	86-97
m_b 7.0 (M_s 8.3)	0.3-1.0	2.7-4

A number of assumptions about the seismic behavior of New Madrid were necessary in order to generate the above probability ranges. The approach used and the assumptions that went into the final probability estimates are described briefly below.

Probability estimates require that the seismic zone behaves in a roughly predictable or period manner. This cannot be proven for large New Madrid events because of an incomplete data set over many seismic cycles, but smaller earthquakes exhibit a well behaved recurrence pattern. Therefore, the authors took instrumentally recorded data from the past nine years (see Figure 1) and a historical list of earthquakes of the past 158 years, determined the recurrence relationships for this data set, and then extrapolated to large magnitudes. This yielded an estimate of the average recurrence or repeat time in years between New Madrid earthquakes for a given magnitude range. For m_b 6.0, the average repeat time is 70 years. (The last such event occurred 90 years ago in 1895.) For m_b 7.0 (M_s 8.3). the average repeat time is 550 years. (The last such event was in 1812, 173 years ago.) These estimates apply to data from the entire region shown in Figure 1. If only the small region is considered (within the rectangle of Figure 1), repeat times approximately double. There are sound geophysical reasons for choosing the larger source zone.

Once the average repeat time is established, both cumulative and conditional probabilities can be determined. Cumulative probability tells us the likelihood that a quake of a certain magnitude would have occurred by now (the present) given the date of the last occurrence and the average recurrence interval. Conditional probability estimates the likelihood of occurrence during a future specified time period (i.e., 15 and 50 years--this study). Obviously, conditional probabilities are of greater interest than cumulative and are therefore emphasized in this study.

In order to make the final probability computations it is necessary to know the manner in which actual earthquake repeat times, for a given magnitude range, are dispersed about the estimated mean repeat time. This is described statistically in terms of a probability distribution with a given standard deviation. Such information for large magnitude New Madrid events is lacking; the authors' approach, therefore, was to take a number of different distributions and a range of standard deviations from the literature of studies of other active earthquake zones and apply these to New Madrid. This approach allowed for a large uncertainty in the actual (but unknown) behavior of New Madrid. This results in a range of probability values as quoted above rather than a single number.

Figures 3-5 are graphs of Gaussian conditional probabilities from m_b 6.0, m_b 6.6, and m_b 7.0 earthquakes (M_s 6.3, M_s 7.6, and M_s 8.3, respectively), graphs on which one can see the effect that the standard deviation exerts on the probability values. The types of probability distribution employed also have an effect but to a lesser degree. The date of last occurrence, the present (1985), and the mean recurrence time are indicated on the horizontal time axis. Shading illustrates the probability range as standard deviation is varied from 33 percent to 50 percent of the mean repeat time. Calculations were done for four different statistical representations--Gaussian, log-normal, Weilbull, and Poisson--but only Gaussian is shown here. Poisson statistics, which yield a constant conditional probability, are not appropriate for this analysis; therefore, only the Gaussian, log-normal, and Weibull distributions were used to obtain the probability ranges quoted above.

In conclusion, the authors estimate that there is a medium probability of a locally destructive New Madrid earthquake in the next 15 years (40 percent to 63 percent) and a high probability (86 percent to 97 percent) in the next 50 years. The probability for a great New Madrid event is less than 1 percent by the turn of the century and less than 4.0 percent during the next 50 years. These estimates are of necessity based on a number of unproven assumptions about the New Madrid zone; however, every effort was made to take an appropriate and comprehensive range of estimates in order to bracket the actual probability for future destructive earthquakes in the central United States.

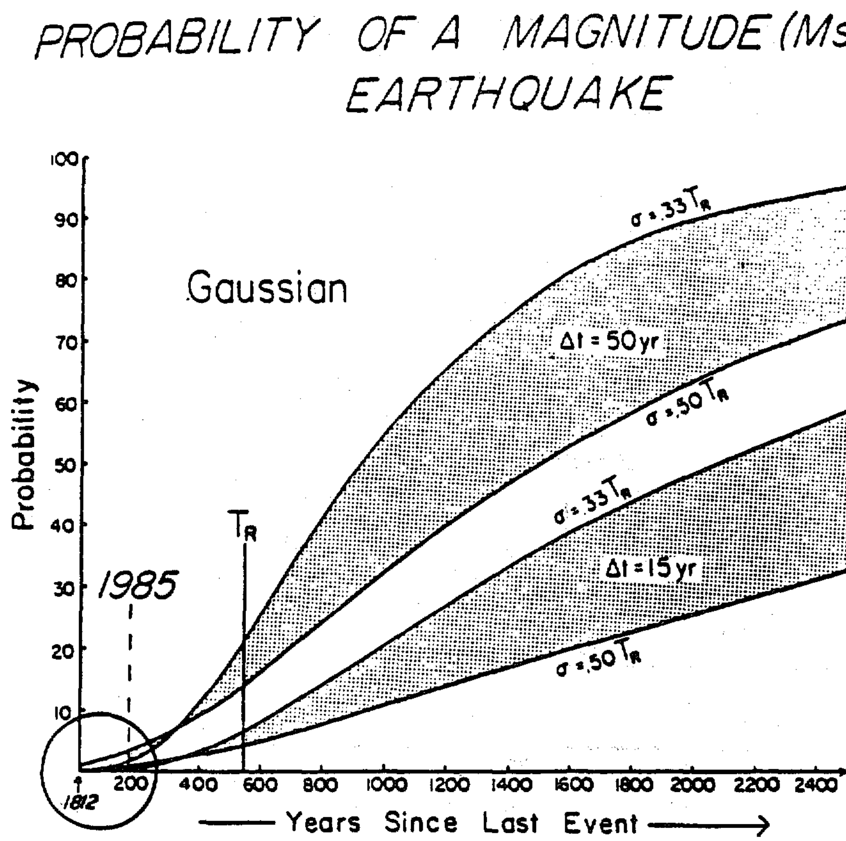

FIGURE 3(a) Gaussian conditional probability computed for magnitude m_b 7.0 (M_s 8.3) earthquake. The last such event occurred in 1812 and the mean repeat time (T_R) is 550 years. The shaded region represents the range of conditional probability as the standard deviation is varied from 33 percent to 50 percent of T_R. Future time intervals (Δt) of 15 and 50 years are depicted.

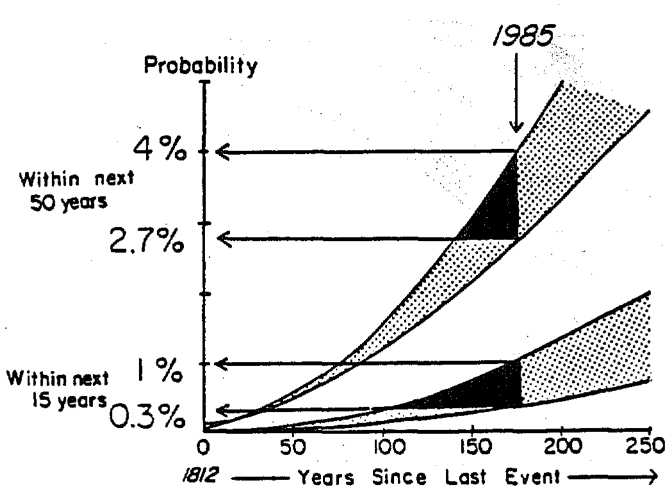

FIGURE 3(b) An expanded view of the circled region near the origin of Figure 3(a). The probability ranges are those quoted in the text.

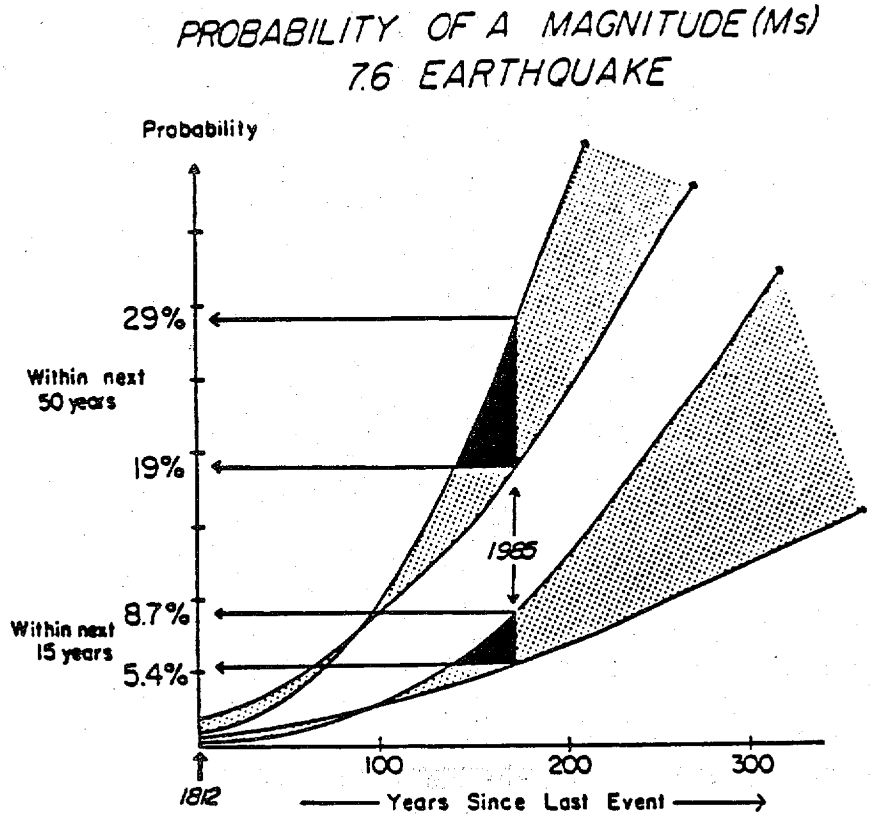

FIGURE 4 Conditional probability representation of an m_b 6.6/M_S 7.6 earthquake. Graph description follows Figure 3(a).

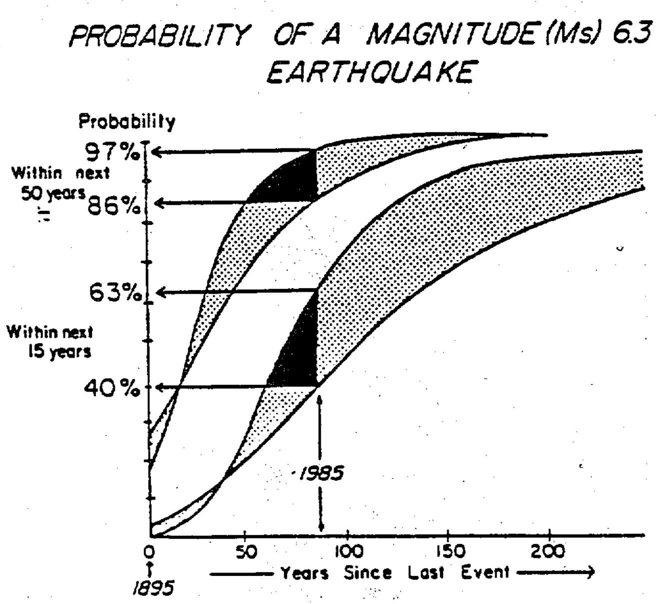

FIGURE 5 Conditional probability representation of m_b 6.0/M_S 6.3 earthquake. Graph description follows Figure 3(a).

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